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RESEARCH MEMORANDUM

EFFECT OF BOUNDARY SOLIDITY ON PLANING LIFT OBTAINED IN A HIGH-SPEED WATER JET WITH A SINGLE LONGITUDINAL SLOT IN EACH RIGID BOUNDARY

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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EFFECT OF BOUNDARY SOLIDITY ON PLANING LIFT OBTAINED IN A HIGH-SPEED WATER JET WITH A SINGLE LONGITUDINAL SLOT IN EACH RIGID BOUNDARY

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SUMMARY

Hydrodynamic planing-lift forces were obtained with a 0.72-inch-beam flat plate at 200 feet per second in a rectangular jet 3.00 inches wide and 1.50 inches deep. The jet was enclosed by a series of rigid side and bottom boundaries, each with a longitudinal slot in the center. The width of the slots was varied to obtain boundary solidities from 0 percent (free boundary) to 100 percent (solid boundary). For each of these boundary configurations, tests were made at trims from 8° to 20° and wetted-length—beam ratios from 2.5 to 6.7, which corresponded to drafts from 13 to 100 percent of the jet depth. At selected test conditions, data were obtained also at 100 feet per second to determine effect of speed.

With increase in boundary solidity from 0 to 100 percent, the hydrodynamic planing lift increased from values below to values above those computed for infinite boundaries. The effect of the boundary became greater with increased penetration of the jet by the model. At a solidity of about 72 percent, the jet data for all penetrations were within 5 percent of the infinite-boundary values calculated by the method of NACA Technical Note 3939. In a free jet (zero solidity) similar agreement was obtained only for drafts up to 50 percent of the jet depth. The influence of speed was small.

INTRODUCTION

Preliminary investigations of the possibilities of obtaining high-speed planing data on a free water jet (no solid boundaries) have been reported in references 1 and 2. The results of these investigations indicated that, because of the influence of the finite free-jet boundaries, the planing lift obtained in the free jet was less than that obtained in towing tanks. In reference 3 tests showed that, for trims up to 20° and length-beam ratios up to 4, the effect of the boundaries of the free jet become negligible only when the width of the jet is at least 3 model beams and the depth of the jet is at least 2 model beams. For smaller jet widths or depths, planing lift values obtained in the free jet were reduced.

The purpose of this investigation was to study the usefulness of slotted rigid boundaries in extending the jet penetrations for which data obtained in the water jet would be in good agreement with towing-tank data. The solidity of the side and bottom boundaries was varied from 0 to 100 percent by using a single longitudinal slot of appropriate width in each boundary. The lift coefficients obtained were compared with those computed by the equation of Shuford given in reference 4.

SYMBOLS

A aspect ratio, b/l

b beam of model, 0.72 in.

$C_{D,c}$ cross flow drag coefficient, 0.94

$C_{L,j}$ lift coefficient obtained in jet, $\frac{L}{\frac{1}{2}\rho SV^2}$

$C_{L,t}$ computed infinite-boundary lift coefficient, $\left(0.5\pi \frac{A}{1 + A} \tau \cos^2\tau + C_{D,c} \sin^2\tau \cos^3\tau\right)$

d draft of model from the top of the side boundary, in.

H depth of jet, 1.50 in.

L hydrodynamic lift on model, lb

l wetted length of model, in.

p static pressure in water tank at level of nozzle entrance, lb/sq in. gage

S wetted area of model, $\frac{bl}{144}$, sq ft

V speed, equivalent to pressure p, $\sqrt{\frac{144p}{\rho/2}}$, fps

τ trim or angle between bottom of model and horizontal, deg

ρ mass density of fresh water, 1.94 slugs/cu ft

APPARATUS AND PROCEDURE

Apparatus

A schematic drawing of the equipment is shown in figure 1. A description of the construction and operation of this apparatus is given in reference 1. The test jet is produced by introducing high-pressure air above the surface of the water in the tank and thus forcing the water out of a nozzle at the bottom of the tank. In this investigation, the nozzle exit was 3.00 inches wide and 1.50 inches deep. The jet was discharged through one of the several rigid-boundary configurations investigated. A simple cantilever strain-gage balance was used to measure lift.

Boundaries

As shown in figures 2 and 3, each rigid-boundary assembly consisted of a bottom and two sides attached to the nozzle frame in such a way that the inner surfaces were alined accurately with the nozzle exit. These was a gap of about 1/2 inch between the nozzle exit and the boundaries to permit passage of the control gate across the nozzle exit. All upstream edges of the boundaries and their supports were beveled outboard of the jet in such a way that all water extraneous to the jet proper was channeled off. The boundaries were about 18 inches long and 1/4 inch thick. Each had a central longitudinal slot running its full length. The length of slot uninterrupted by crossties began about 1.5 inches from the nozzle exit and extended to a distance of about 14.5 inches from the nozzle exit. For photographic-lighting purposes, the bottom boundaries of the 92-, 96-, and 100-percent-solid boundaries were made of reinforced clear plastic. All other boundaries were made of steel.

Slot dimensions for the five rigid-boundary configurations investigated are given in figure 3. In a given configuration, the percent opening was the same for each slotted boundary. Thus, for a solidity of 83 percent, the width of the slot would be 17 percent of the width of the wall containing it. Percent solidities investigated were zero (free boundary), 60, 83, 92, 96, and 100 (solid boundary with no slots).

Models

The models were rectangular blocks of clear plastic with a beam of 0.72 inch and a depth of 1.00 inch. Details of the models are given in figure 4. Transverse, 0.03-inch-diameter holes were drilled parallel to and 0.06 inch from the bottom, at intervals of 0.20 inch. These holes were filled with red paint as an aid in measuring wetted length.

Five models of various lengths were used, one for each wetted length investigated. The models were about 3, 4, $4\frac{1}{2}$, $6\frac{1}{2}$, and $7\frac{1}{2}$ inches long, respectively. In order to minimize the bending moment on the models, they were designed to have the stagnation line about 0.5 inch forward of the staff (fig. 5). The longer models had an additional support at the aft end to insure rigidity (fig. 2). Brass wedges were used between the models and staff to obtain desired trims.

Procedure

Tests were made at fixed trims of 8°, 12°, 16°, and 20° and at length-beam ratios of approximately 2.5, 3.6, 4.4, 5.6, and 6.7. This range of trim and wetted-length parameters corresponded to model drafts varying from 13 to 100 percent of the depth of the jet. The tests were made at 200 feet per second at all trims and length-beam ratios for each of the six boundary configurations investigated. Additional tests were made at 100 feet per second for a length-beam ratio of 5.6 at all trims and solidities and also for a solidity of 83 percent at all trims and length-beam ratios.

The model was placed in the jet in such a way that the stagnation line would be about 3.0 inches downstream of the nozzle exit. Before each run, the draft of the model was set by sighting with a theodolite, the trim was checked, and the initial air pressure was set to give the desired speed value. The speed of the jet was calculated by assuming total conversion of the static pressure at the nozzle entrance. A continuous record of the static pressure and the hydrodynamic lift on the model was made on a multichannel oscillograph with 0.01-second timing lines. The hydrodynamic lift was read at that point on the record where the net displacement of the pressure trace corresponded to the desired speed. Wetted length was recorded on color film by a 16-millimeter movie camera which made a correlating mark on the oscillograph record. A single light shining through the model into the camera was the only lighting used for these motion pictures (figs. 1 and 2). A photograph of a typical run showing the wetted length is given in figure 5.

The estimated accuracy of measurement was within the following limits:

Lift, percent of measurements	±2.0
Trim, deg	±0.05
Wetted length, in.	±0.05
Speed, fps	±0.5

RESULTS AND DISCUSSION

Jet Data

The data obtained at a speed of 200 feet per second are presented in figure 6. For each boundary solidity, lift coefficient is plotted against length-beam ratio with trim as a constant parameter. The symbols represent actual test data. The curves were obtained by cross-fairing the test results against trim and boundary solidity as well as length-beam ratio. The lack of scatter indicates that the data were consistent and varied continuously with all parameters involved.

For all trims and length-beam ratios investigated, the "pile-up" (extension of wetted length above the undisturbed water level) was approximately 0.4 inch or about one-half the beam of the model. Thus, for the data obtained in this investigation, the wetted length l may be related approximately to the draft d and the trim τ by the equation $l = \frac{b}{2} + \frac{d}{\sin \tau}$. Infinite-boundary planing data also indicate (ref. 5) that the pile-up in front of a planing surface is primarily a function of its beam.

Effects of Boundary Solidity

At the higher solidities and trims investigated, the curves in figure 6 indicate an increase in lift coefficient $C_{L,j}$ with increase in length-beam ratio - an effect opposite to that for the infinite-boundary planing data. This increase in $C_{L,j}$ is due to restriction of the flow by the excessively solid boundary.

The effect of solidity on the jet lift coefficient $C_{L,j}$ is shown in figure 7 for the boundary configurations investigated. The jet data

$C_{L,j}$ expressed as a ratio of corresponding theoretical values $C_{L,t}$ are plotted against percent solidity for each combination of trim and length-beam ratio investigated. Also shown is the jet penetration d/H corresponding to these combinations of parameters. The theoretical values of lift coefficient were computed by the method developed by Shuford (ref. 4) which has been found to be in good agreement with a wide variety of towing-tank data. The formula used was

$$C_{L,t} = 0.5\pi \frac{A}{1 + A} \tau \cos^2 + 0.94 \sin^2\tau \cos^3\tau$$

The value of 0.94 was chosen for the crossflow drag coefficient $C_{D,c}$ because it gave theoretical lift coefficients $C_{L,t}$ in best agreement with data obtained in Langley tank no. 2 for a model of the same size and construction (ref. 3).

With an increase in solidity from 0 to about 50 percent, there was little change in the ratio $C_{L,j}/C_{L,t}$. With further increase in solidity to 100 percent, this ratio became increasingly large. The effect of increasing the jet penetration was to accentuate the influence of the boundaries. Deeper jet penetrations resulted in small ratios of $C_{L,j}/C_{L,t}$ at the low end of the solidity scale and larger ratios of $C_{L,j}/C_{L,t}$ at the high end of the solidity scale.

Optimum Solidity

With an increase in boundary solidity from 0 to 100 percent, the ratio of the lift data obtained in the jet $C_{L,j}$ to the theoretical infinite-boundary values $C_{L,t}$ increased from values less than unity to values considerably larger than unity (fig. 7). At a given trim, the solidities at which the ratio $C_{L,j}/C_{L,t}$ varied least with length-beam ratio were approximately 40 percent for the data at 8°, 67 percent for the data at 12° and 74 percent for the data at 16° and 20°. However, at a solidity of about 72 percent the experimental lift coefficients obtained in the jet were within 5 percent of the calculated infinite-boundary values for all trims and length-beam ratios investigated. These test parameters corresponded to drafts up to 100 percent of the jet depth.

In the free water jet (zero solidity data) agreement to within 5 percent was obtained only for drafts up to about 50 percent of the jet depth. At drafts equal to 100 percent of the jet depth, the lift coefficient obtained in the free water jet was 20 percent less than the infinite-boundary value.

A comparison between the jet data $C_{L,j}$ for a solidity of 72 percent and the infinite-boundary data $C_{L,t}$ is given in figure 8 for all trims and length-beam ratios. The jet data were obtained from crossplots of the curves in figure 6. The plots in figure 8 show that, at low trims, the maximum deviation of about 5 percent occurs at the extremes of the range of length-beam ratio investigated, whereas at high trims, it occurs at intermediate length-beam ratios. The different curve shapes indicate that the jet data did not vary with trim and length-beam ratio in quite the same way as the calculated infinite-boundary data. This may be due to other factors such as the coarseness of the boundary configurations and the effect of the interface layer (thin layer of air-water mixture on water-jet surface described in ref. 1).

Effects of Speed

In figure 9(a), the effects of speed are shown by a plot of jet lift coefficient $C_{L,j}$ against percent solidity. Data are presented for a length-beam ratio of 5.56 and trims of 8°, 12°, 16°, and 20° corresponding to jet penetrations d/H of 0.33, 0.50, 0.66, and 0.82, respectively. In some runs, the wetted length did not measure exactly 4.00 inches ($l/b = 5.56$). In these cases, the values of $C_{L,j}$ were corrected to values corresponding to l/b of 5.56 before being plotted in this figure. The correction was made by multiplying the test lift coefficient $C_{L,j}$ by the ratio of the theoretical lift coefficient $C_{L,t}$ ($l/b = 5.56$) to $C_{L,t}$ (measured l/b). The curves are cross-plotted from the curves for 200 feet per second in figure 6. Figure 9(b) shows the effect of speed on $C_{L,j}$ for all length-beam ratios and trims investigated, with a given boundary configuration.

The lift coefficients $C_{L,j}$ for both 100 and 200 feet per second increased as the boundary solidity increased from 0 to 100 percent. The agreement between the data at 100 and 200 feet per second was generally good. The maximum difference was about 6 percent and occurred at maximum solidity and penetration. However, with an increase in boundary solidity from 0 to 100 percent, there was a trend for the jet lift coefficients at 100 feet per second to increase from values below to values above those obtained at 200 feet per second. The curves indicate that there was no apparent variation in $C_{L,j}$ with speed at a solidity of approximately 72 percent.

CONCLUSIONS

The data obtained in this investigation of the effect of boundary solidity on planing lifts obtained in a high-speed water jet with a single longitudinal slot in each boundary indicate the following conclusions:

1. The effect of boundary solidity was to increase the lift from values below that for infinite boundaries at low solidities to values considerably larger at high solidities. This effect increased with increase in jet penetration.

2. For a boundary solidity of about 72 percent, the faired jet data were within 5 percent of the calculated infinite-boundary data for model drafts up to 100 percent of the depth of the jet. In the free water jet, similar agreement was obtained only for drafts up to 50 percent of the jet depth.

3. By proper choice of a simple slotted boundary for a water jet, the influence of its boundaries can be reduced sufficiently so that the jet data will agree with tank data for drafts up to the full depth of the jet.

4. The agreement between the jet data at 100 and 200 feet per second was generally good. There was no apparent effect of speed at a solidity of approximately 72 percent.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 20, 1957.

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2. McGehee, John R., Weinflash, Bernard, and Pelz, Charles A.: The Hydrodynamic Planing Lift of Four Surfaces As Measured in a 200-FPS Free Jet. NACA RM L54F01, 1954.

3. McGehee, John R.: Investigation of the Influence of the Boundaries of a High-Speed Free Water Jet on the Planing Lift of a Flat Plate. NACA RM L56K02, 1957.

4. Shuford, Charles L., Jr.: A Theoretical and Experimental Study of Planing Surfaces Including Effects of Cross Section and Plan Form. NACA TN 3939, 1957.

5. Schnitzer, Emanuel: Theory and Procedure for Determining Loads and Motions in Chine-Immersed Hydrodynamic Impacts of Prismatic Bodies. NACA Rep. 1152, 1953. (Supersedes NACA TN 2813.)

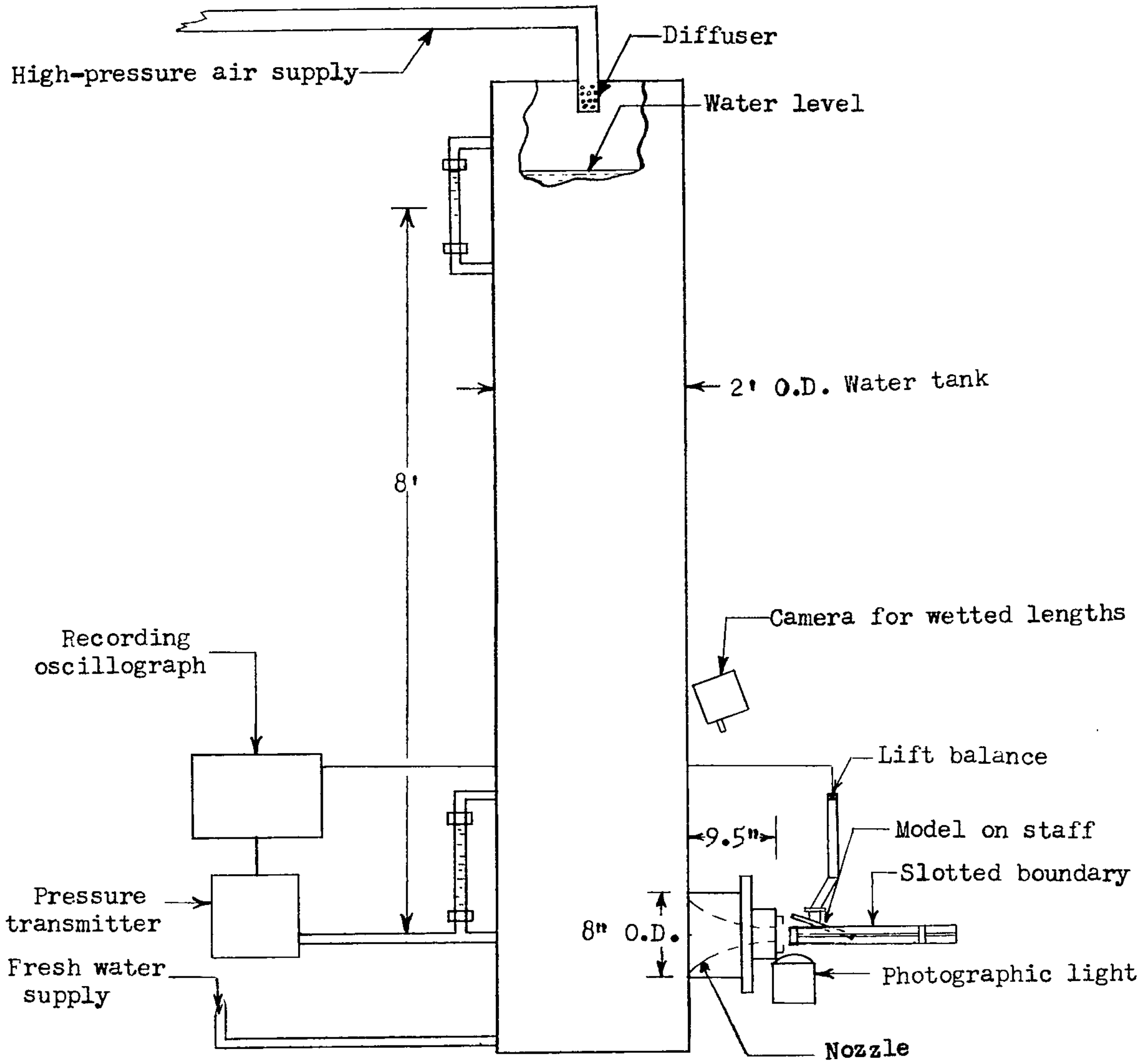

Figure 1.- Schematic drawing of equipment.

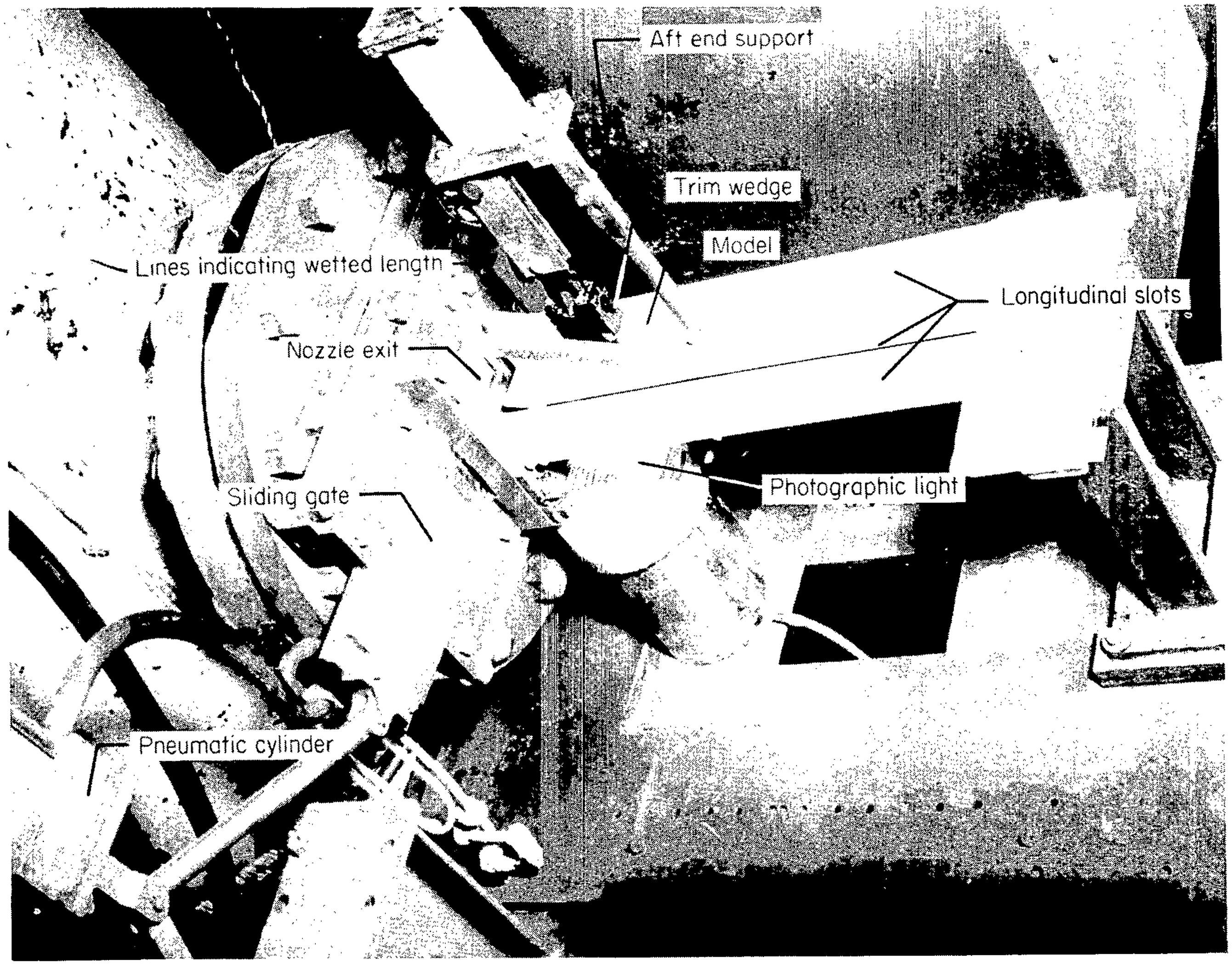

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Figure 2.- Model mounted in slotted boundary (83-percent solidity).

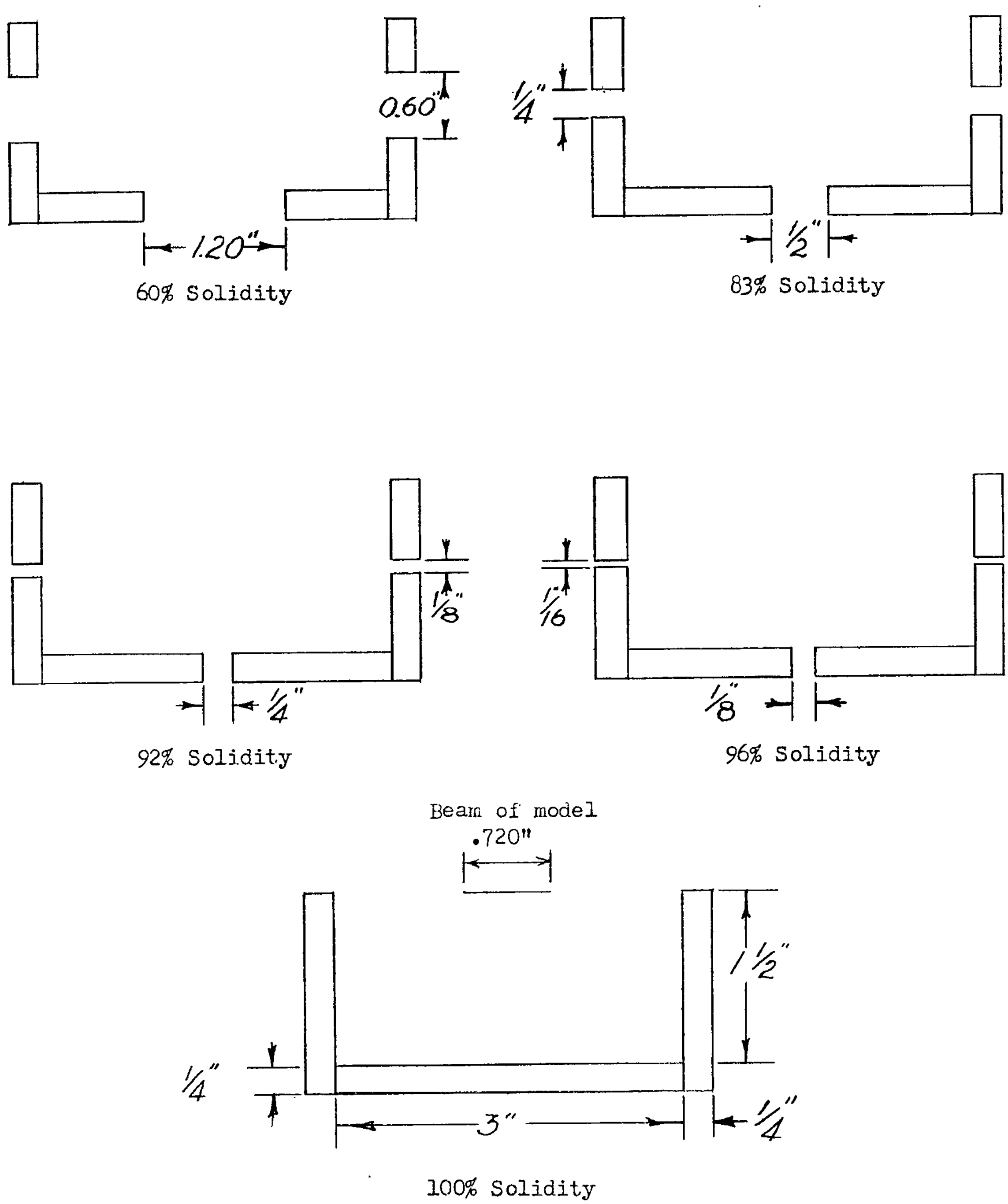
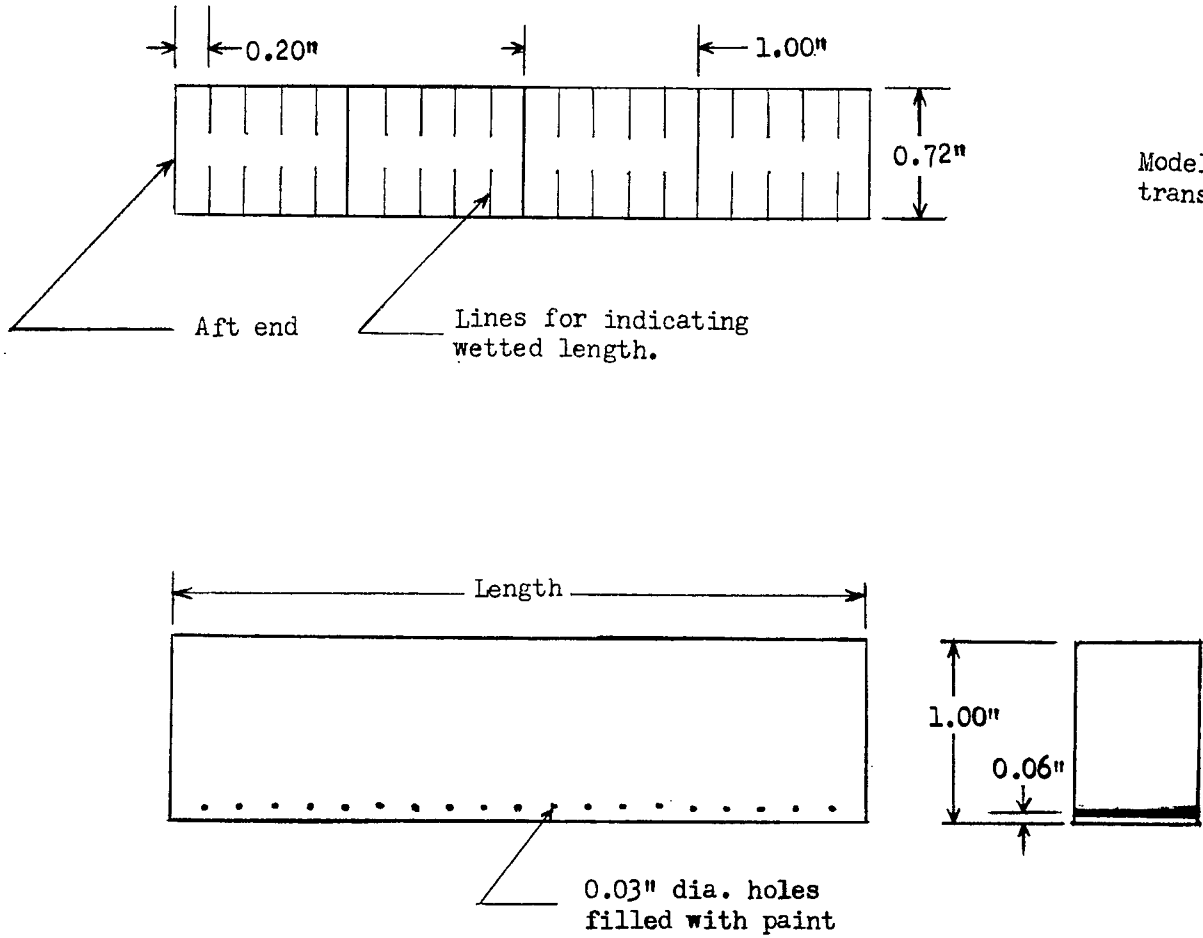


Figure 3.- Boundary configurations.



Models constructed of transparent plastic.

Figure 4.- Details of models.

[redacted]

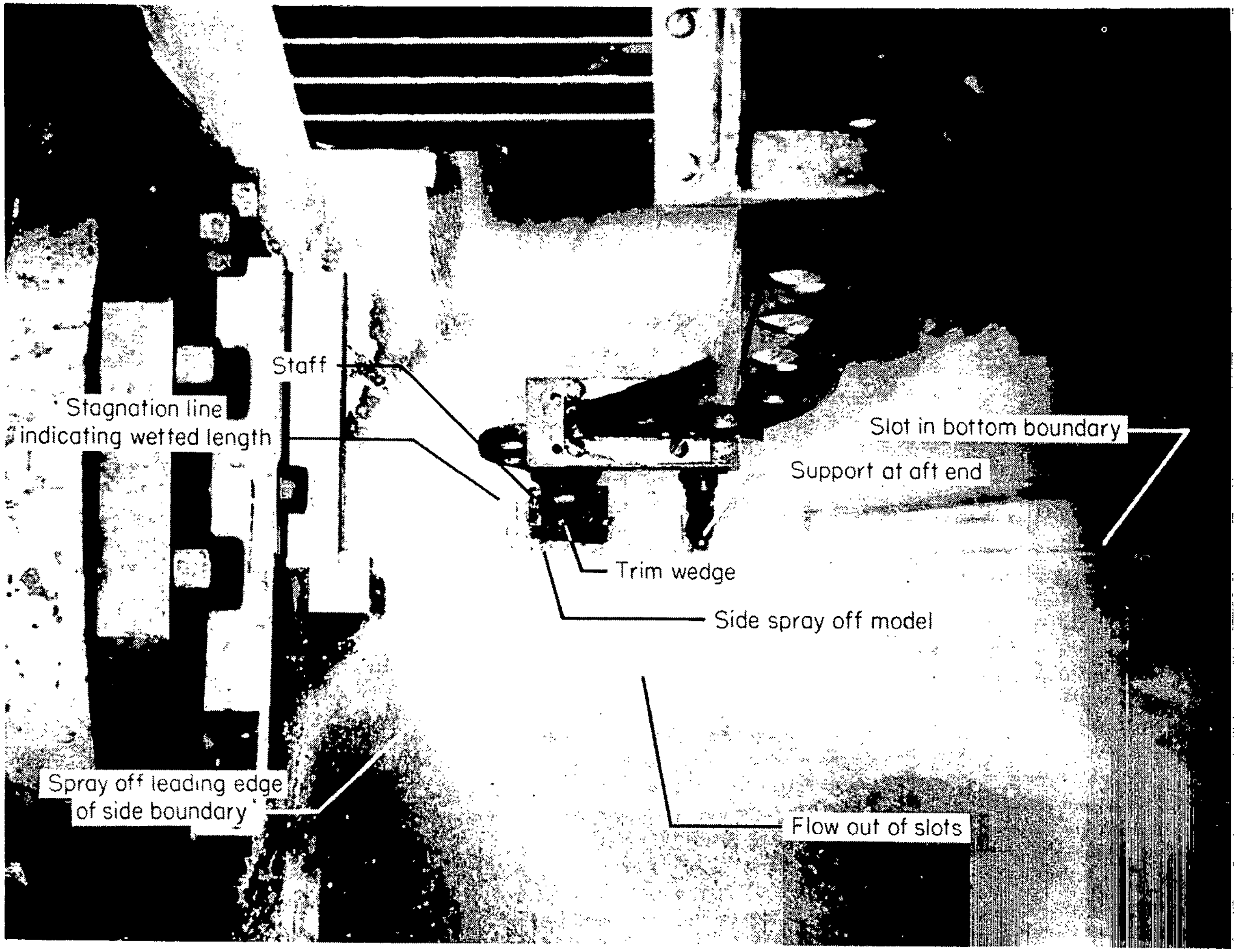


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Figure 5.- Model planing on jet (92-percent solidity). Trim, 20°; wetted length, 4 inches; speed, approximately 200 feet per second.

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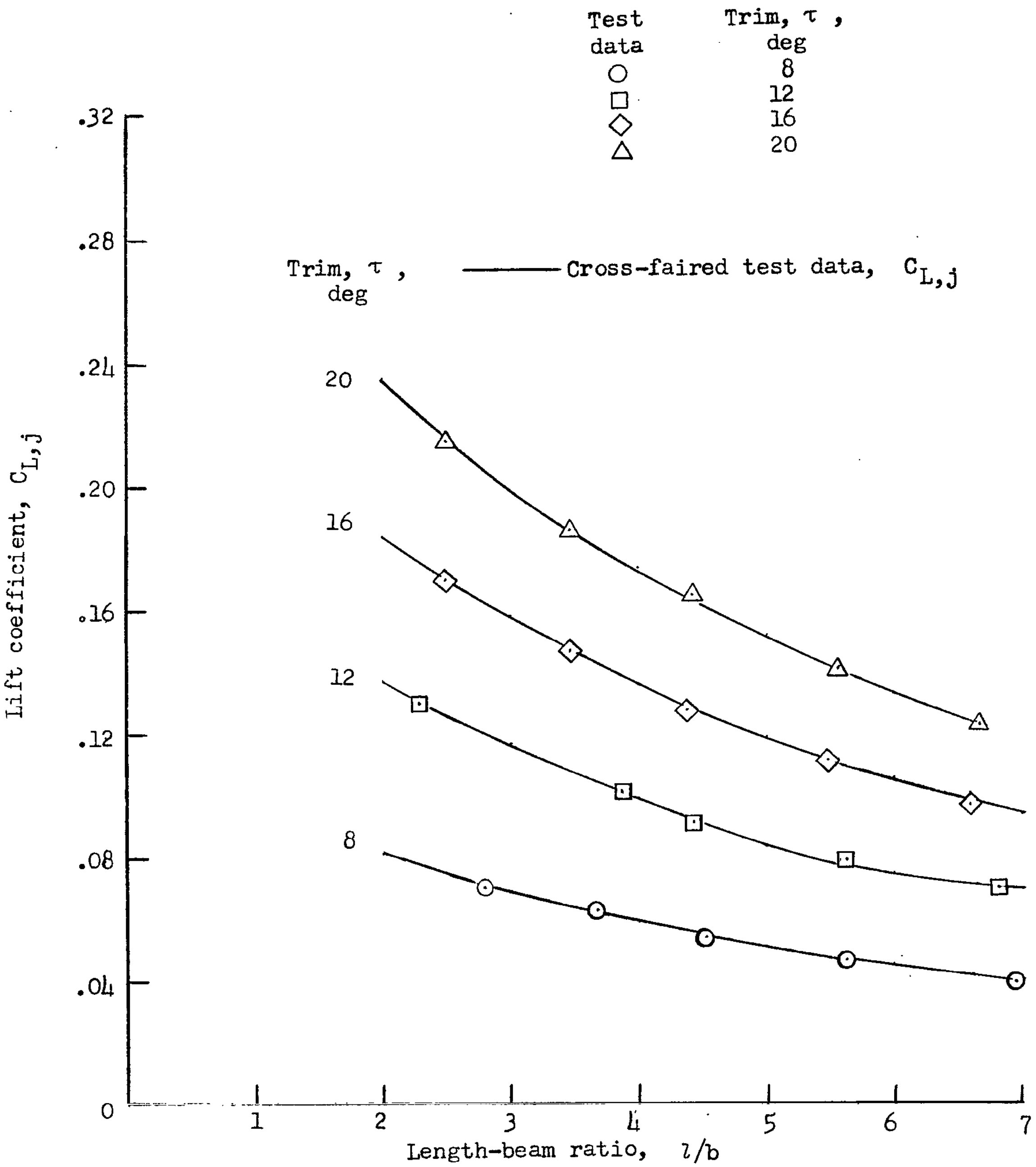
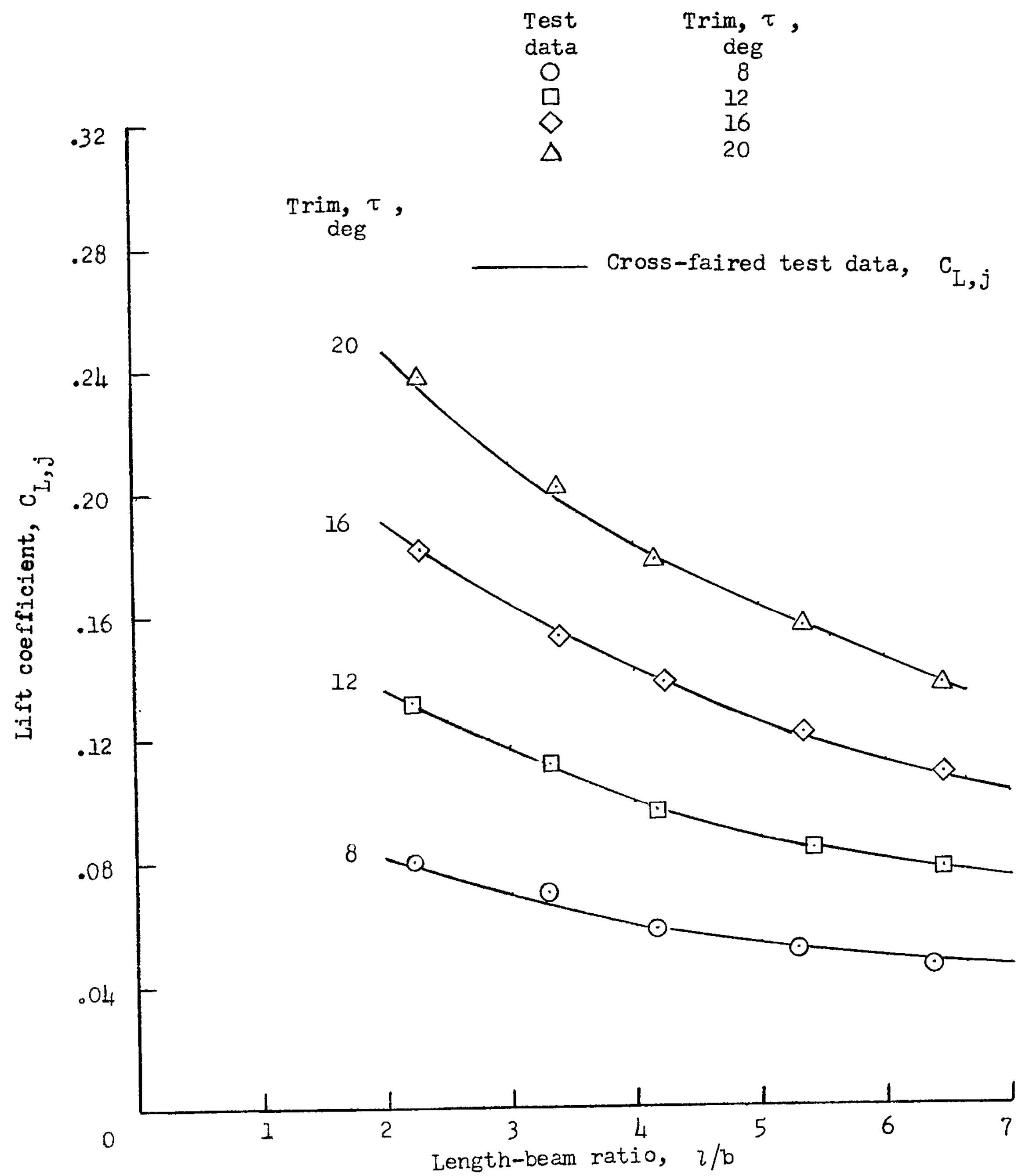


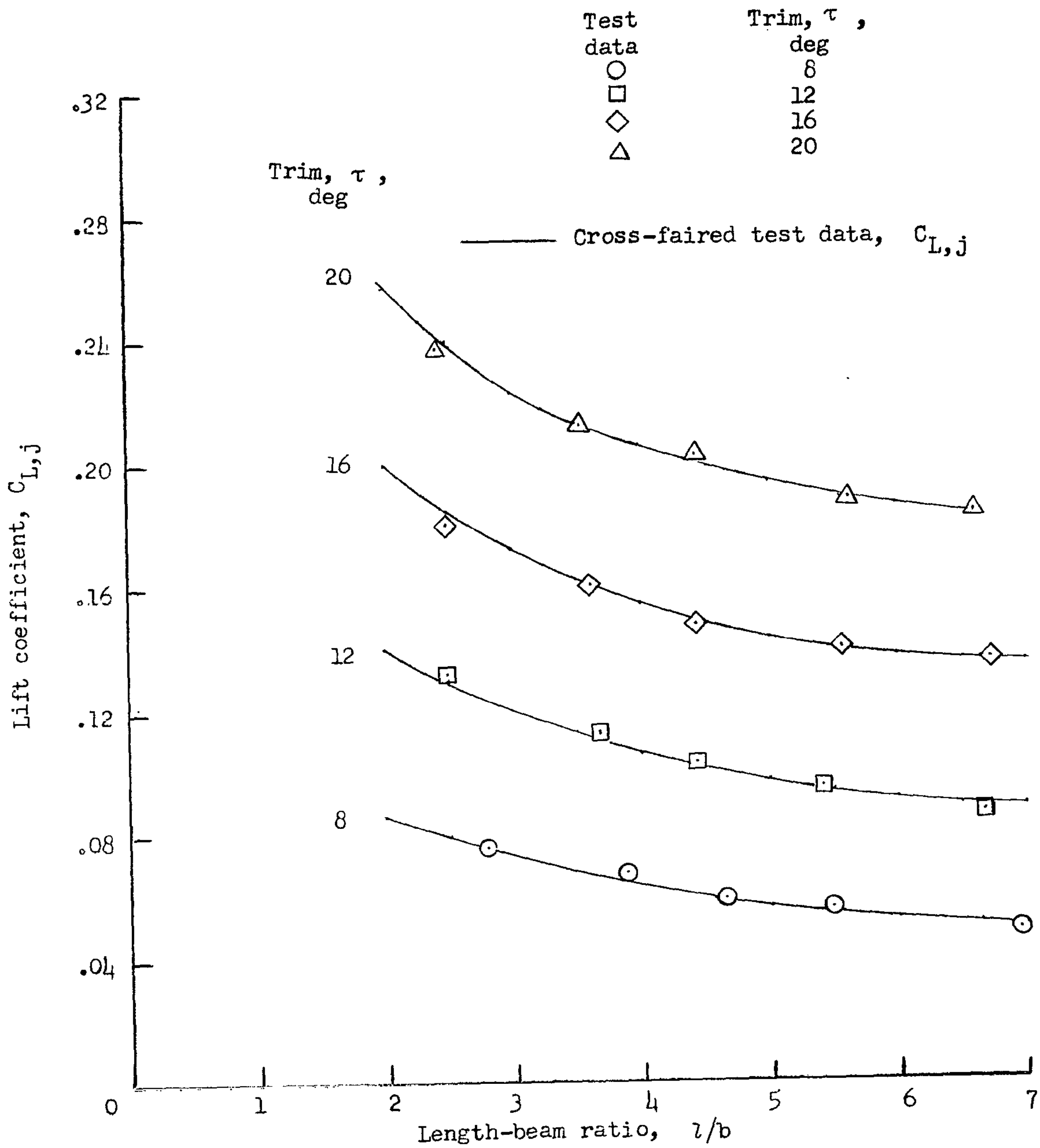
(a) Zero solidity.

Figure 6.- Faired jet data at 200 feet per second.



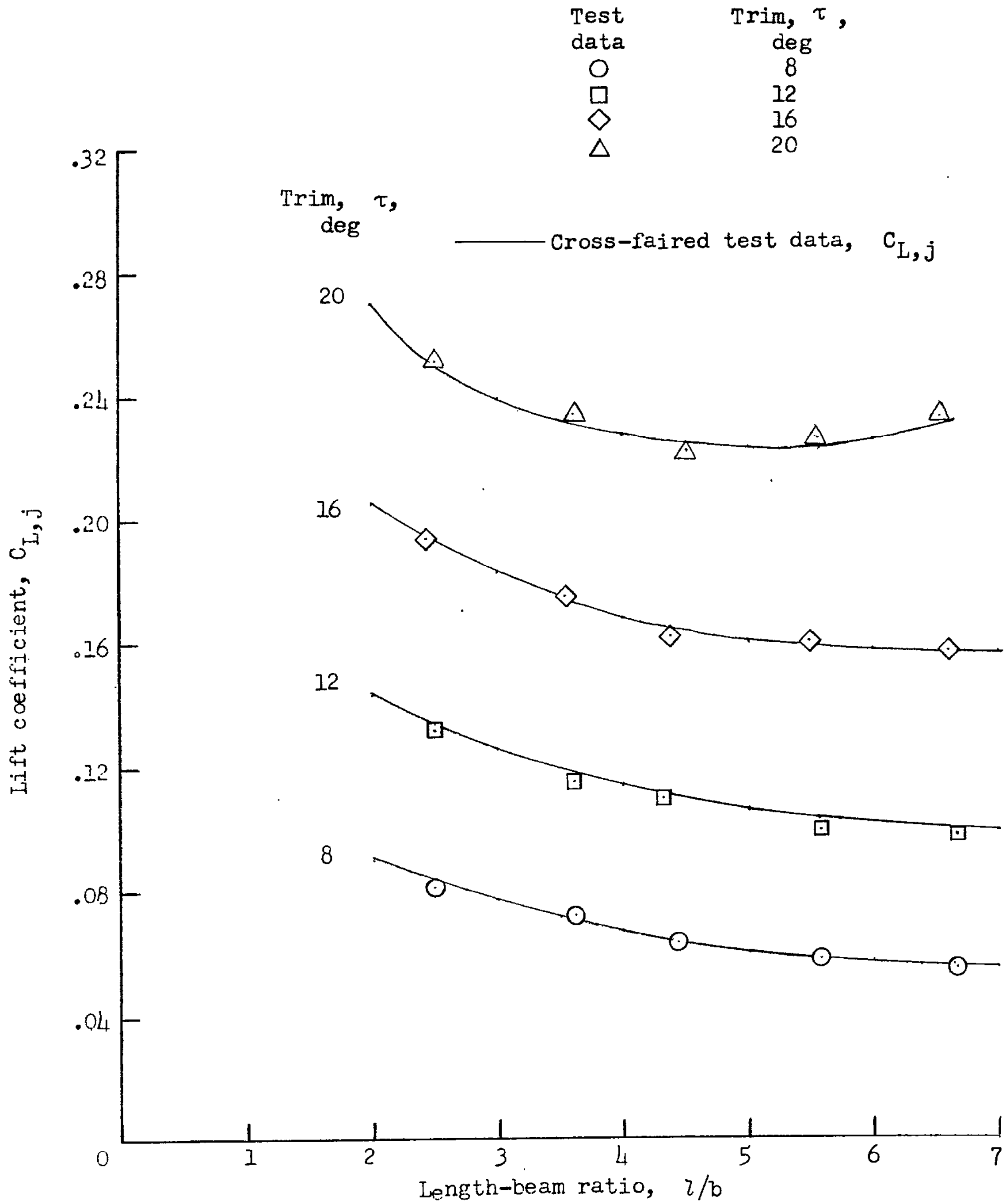
(b) 60-percent solidity.

Figure 6.- Continued.



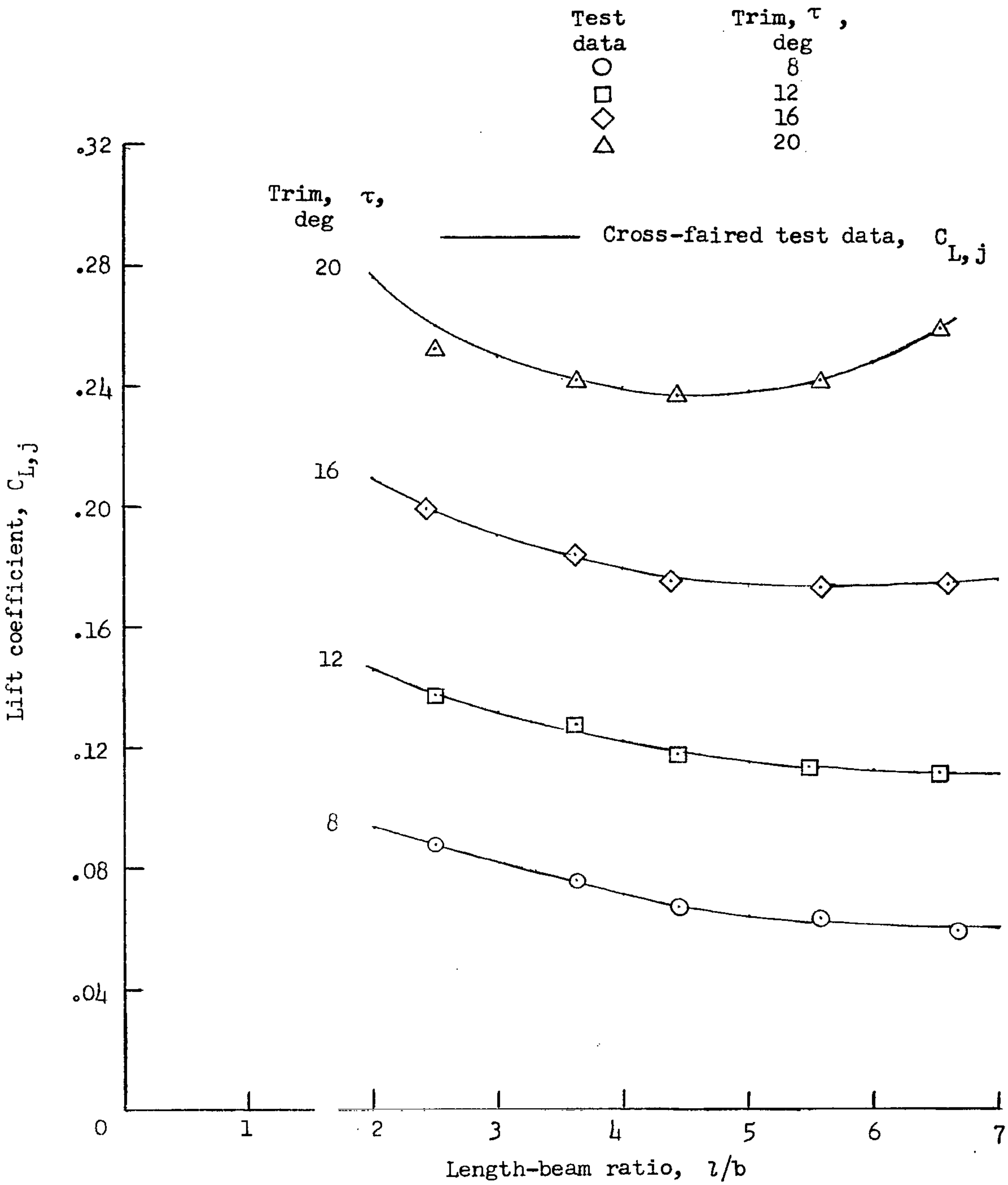
(c) 83-percent solidity.

Figure 6.- Continued.



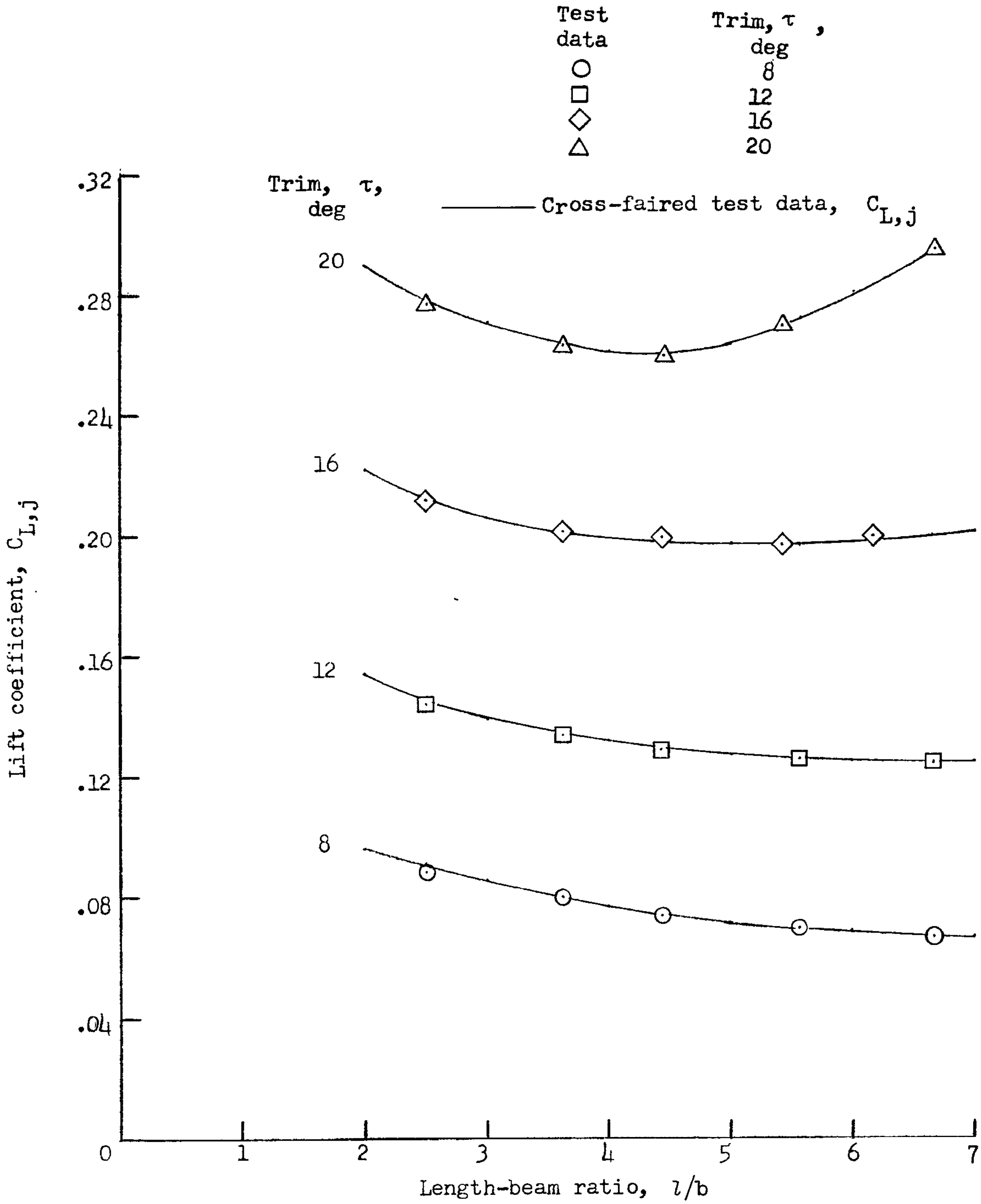
(d) 92-percent solidity.

Figure 6.- Continued.



(e) 96-percent solidity.

Figure 6.- Continued.



(f) 100-percent solidity.

Figure 6.- Concluded.

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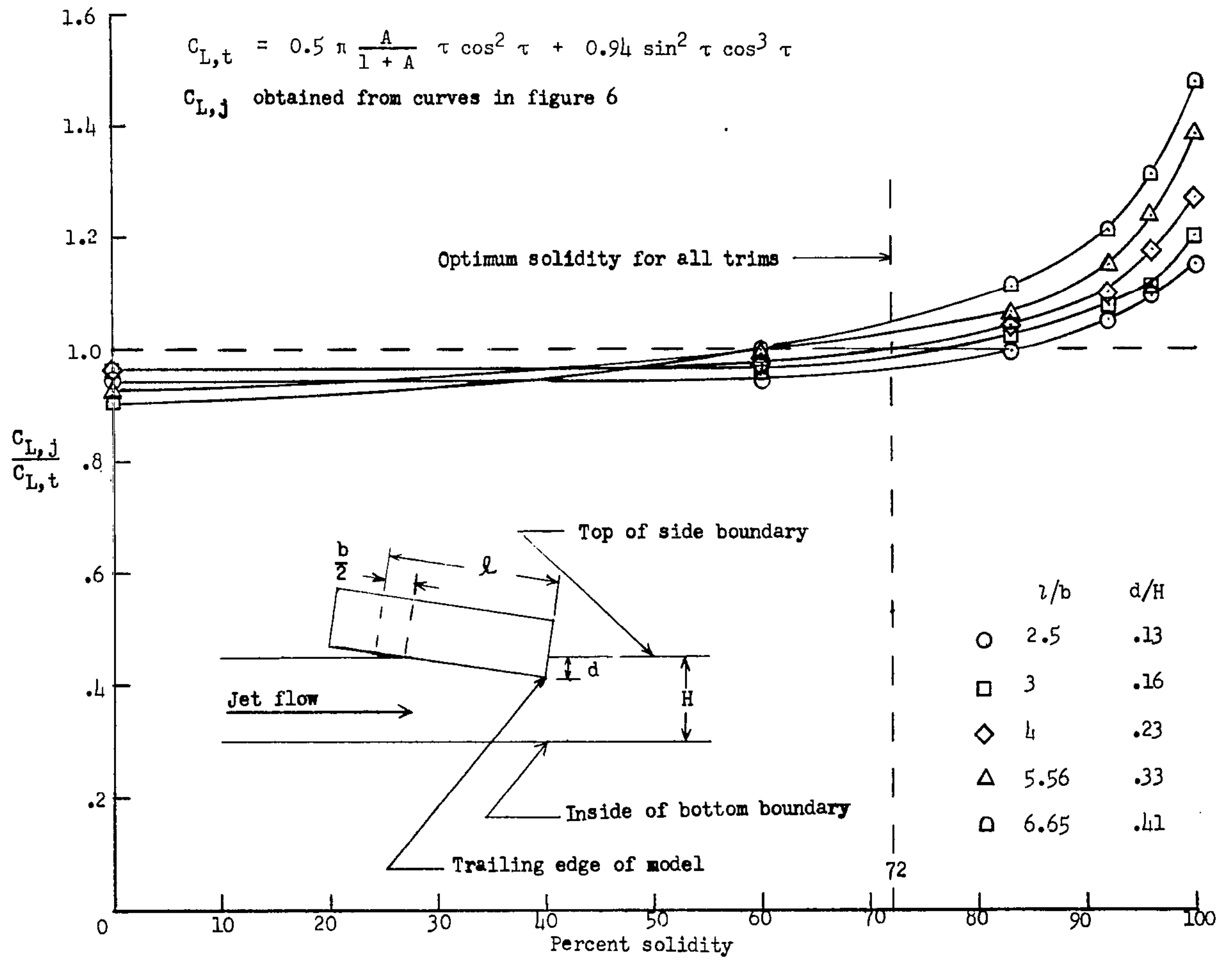
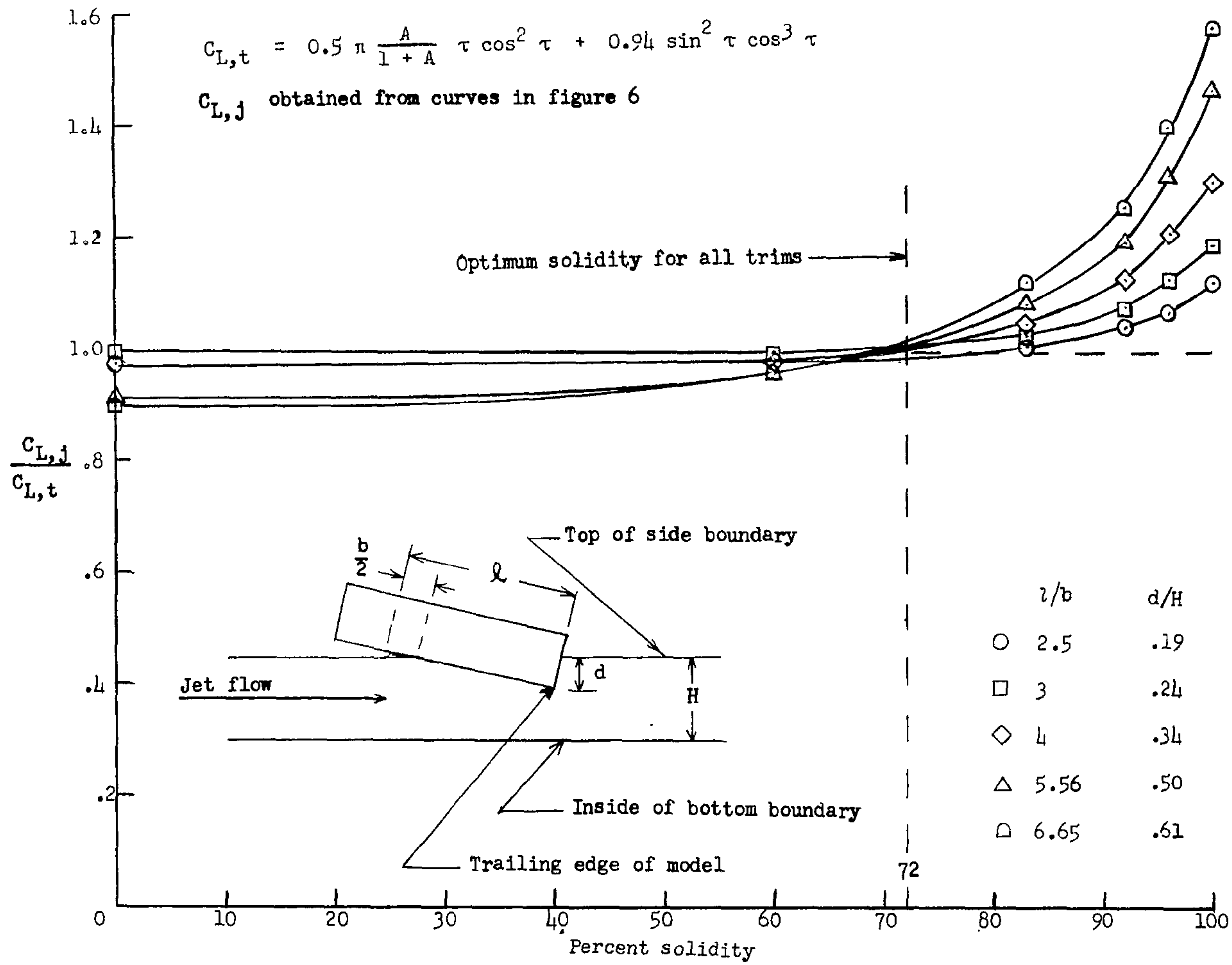


(a) Trim, 8°.

Figure 7.- Effect of boundary solidity on ratio of data obtained in jet to corresponding data obtained in towing tank.



(b) Trim, 12°.

Figure 7.- Continued.

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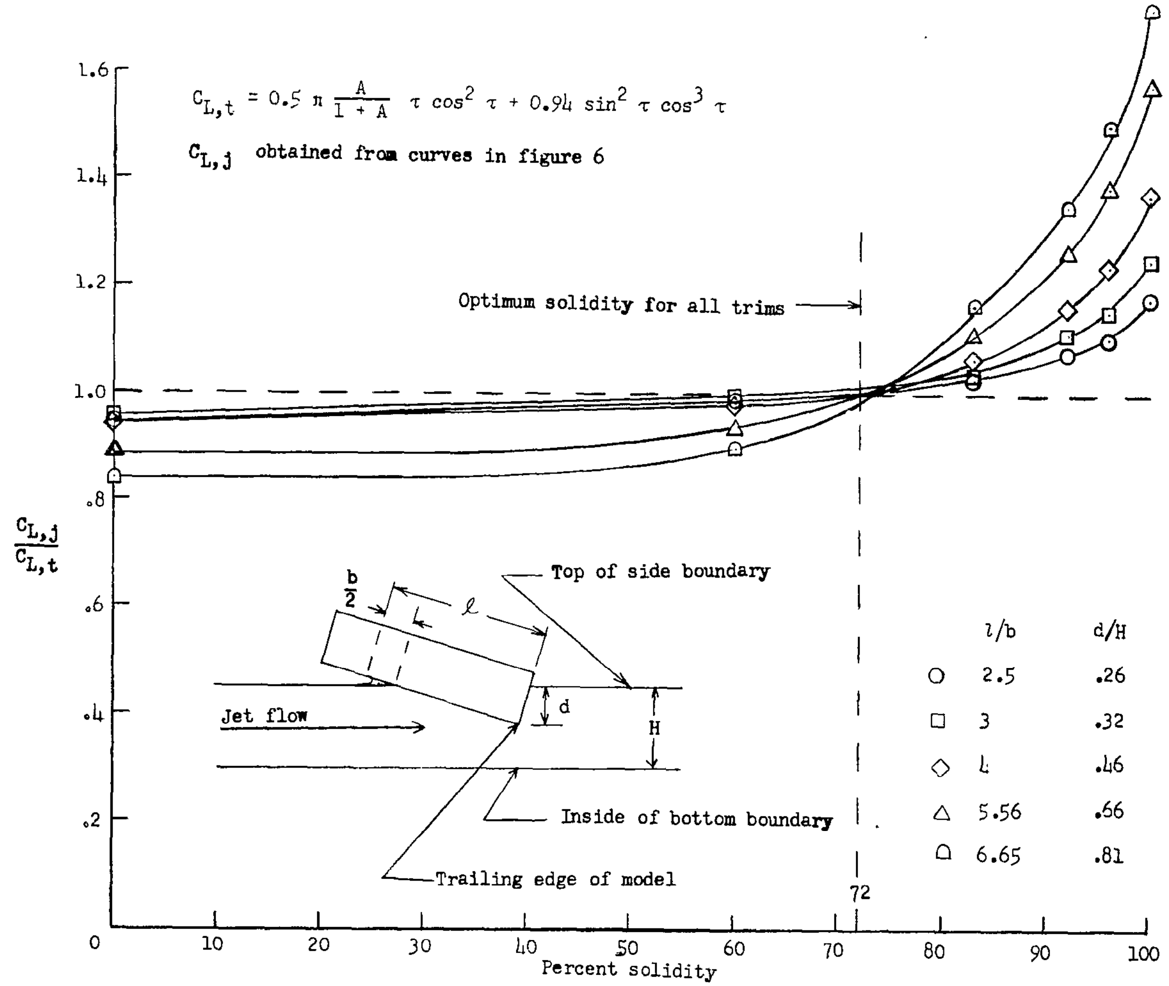
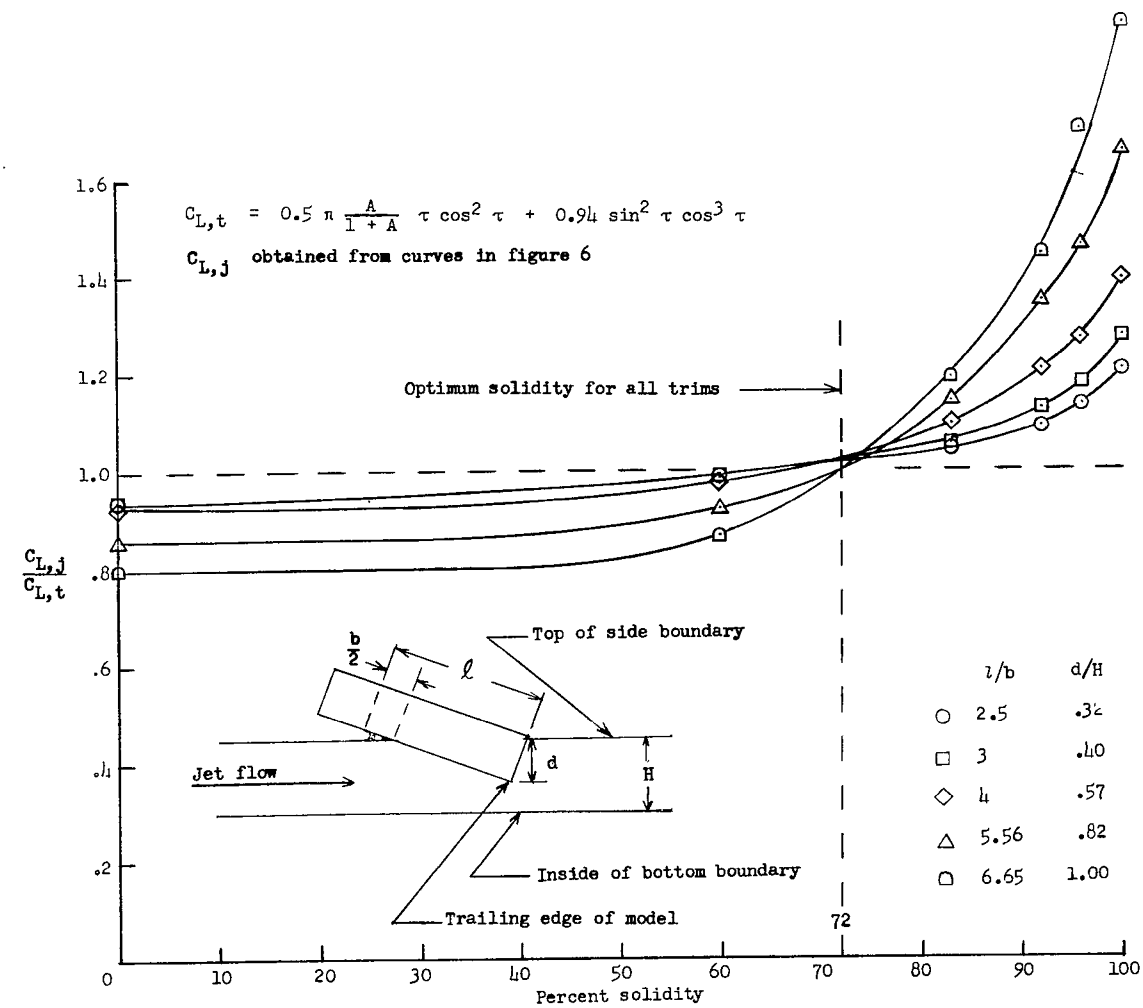


(c) Trim, 16°.

Figure 7.- Continued.



(d) Trim, 20°.

Figure 7.- Concluded.

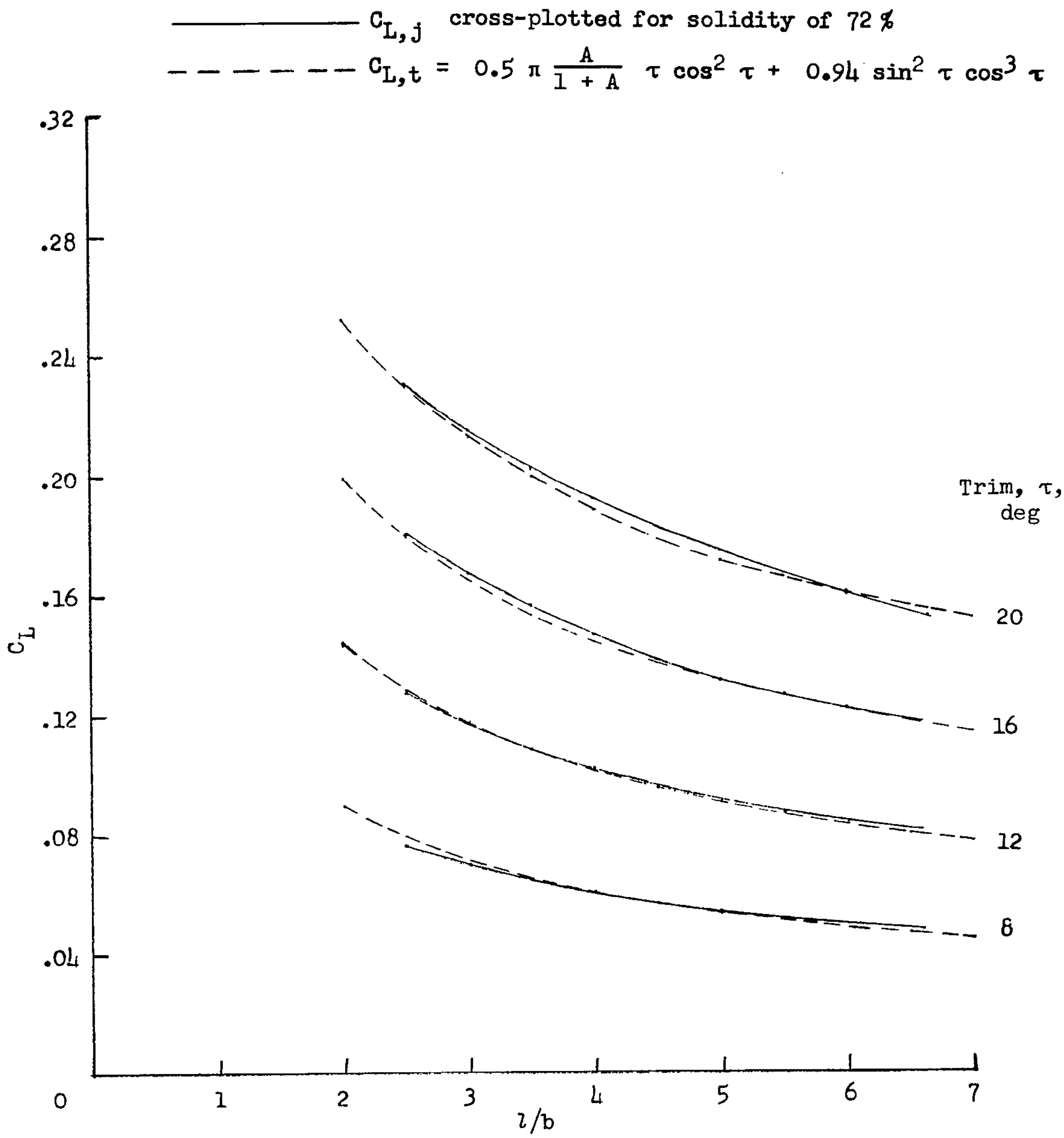
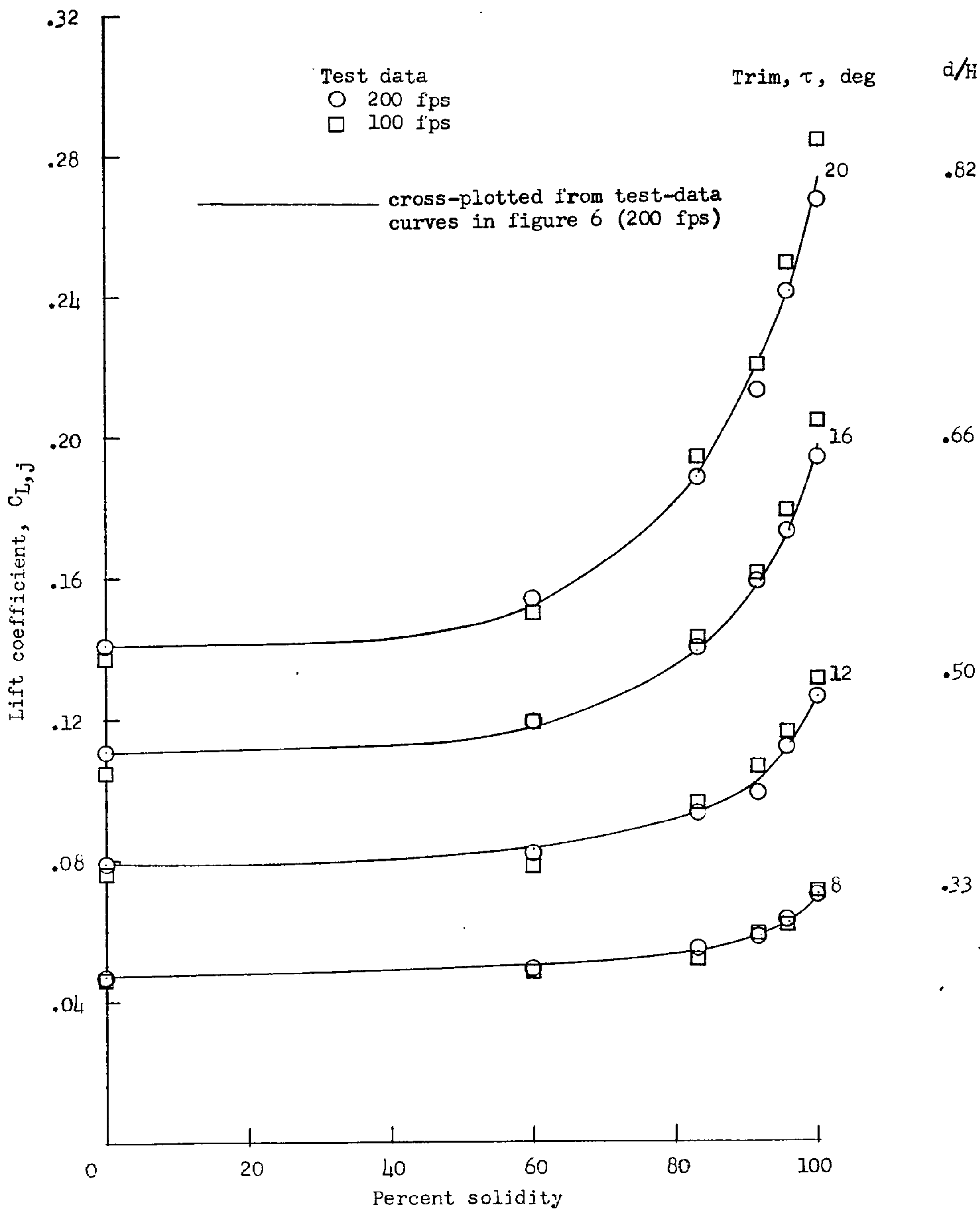
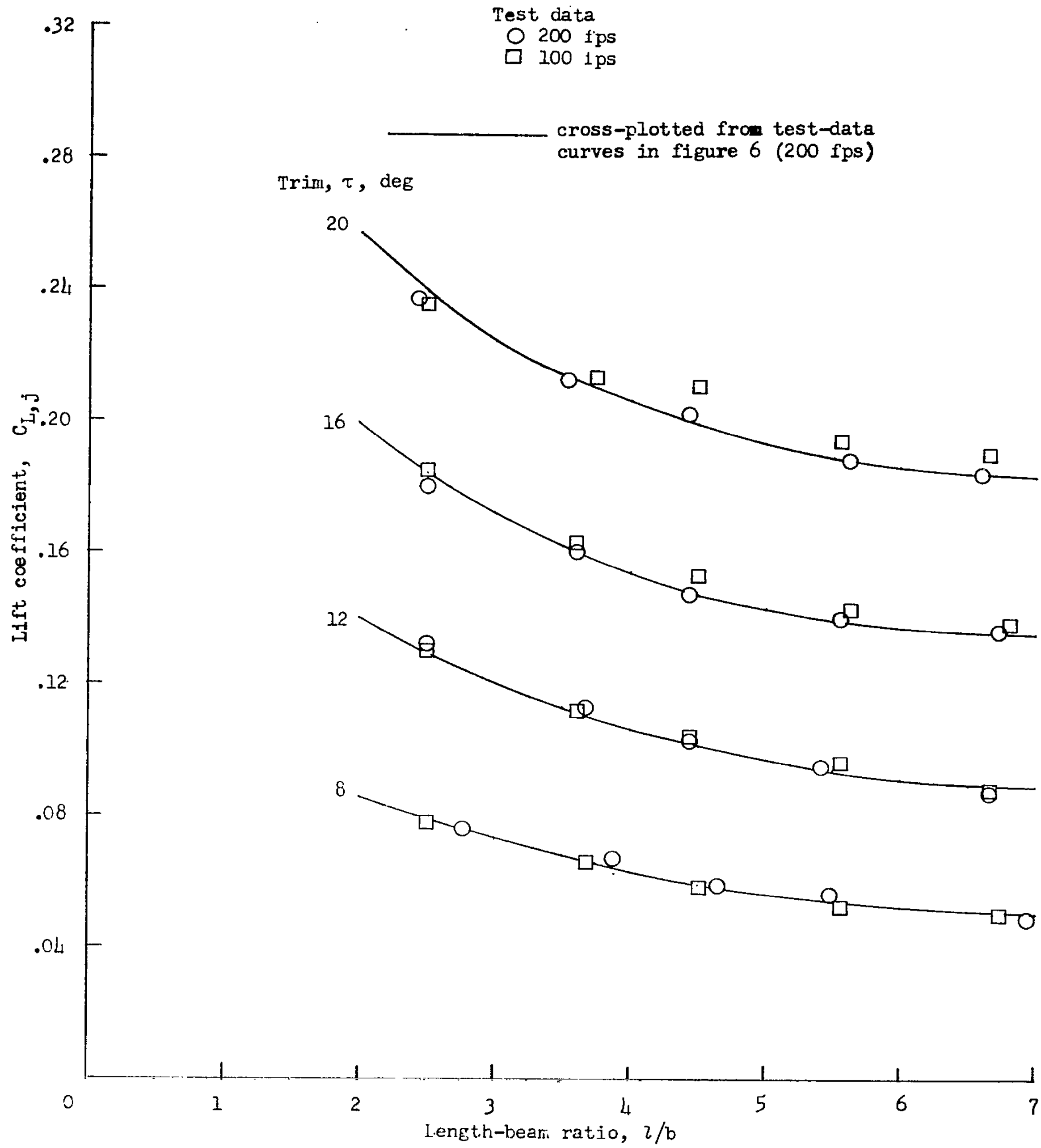


Figure 8.- Comparison of jet data at optimum solidity with corresponding data computed for infinite-boundary conditions with $C_{D,c} = 0.94$.



(a) All configurations. Length-beam ratio, 5.56.

Figure 9.- Effect of speed on data obtained in jet.



(b) 83-percent solidity. All length-beam ratios.

Figure 9.- Concluded.